3D Digitization of Rock Falls for Rock Fall Analysis

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Branch A

Geotechnical Design South 1

Steps for Rockfall Mitigation

1. Obtain Slope Geometry and Geological Mapping
2. Perform Rockfall Computer Simulation
   - Projectile
   - Probability
   - Energy
3. Design Rockfall Mitigation
   - Rockfall Fences
   - Ditch

Limitation of Computer Simulation

- Computer simulations have not been calibrated against actual data – actual rockfall
- Fudge factors have been used in simulation
- Generally provides liberal results
  - Recommendations based on Computer Simulation are often under designed

Research Objectives

- Experiment and develop a rockfall testing protocol and data processing procedure that can
  - Provide reliable data set to be used for site specific model validation
  - Be easily implemented by others
  - Be cost-effective
  - Allow further development and improvement by others

Rockfall Testing Protocol

- Mark reference points
- Survey slope geometry, reference points and camera locations
- Place at least two synchronized camcorders
- Roll rocks off the slopes
- Measure weight, size of rocks

Data Processing Procedure

- Synchronize video files
- Calibrate
- Direct Linear Transformation (DLT) method

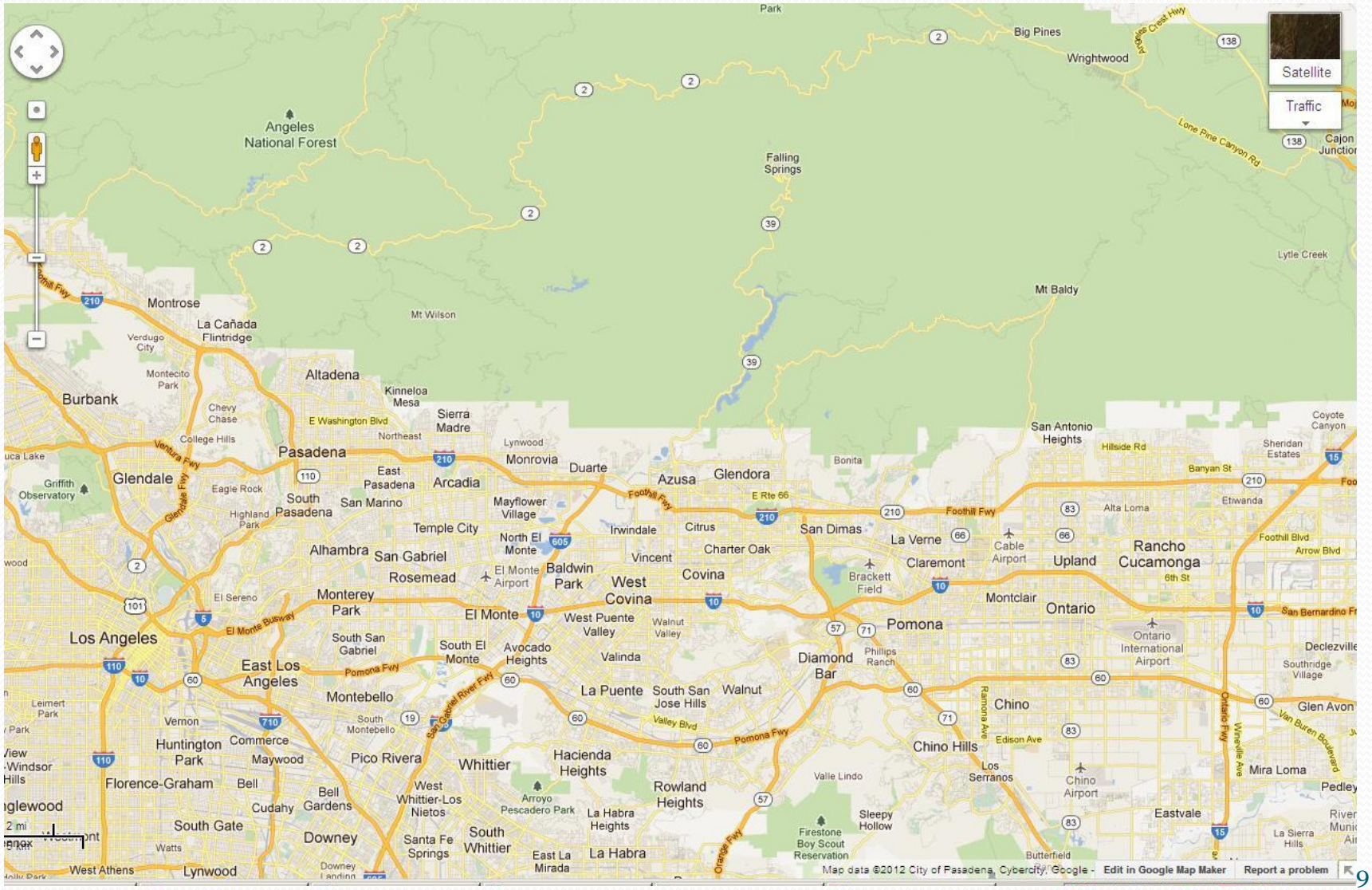
Rockfall Test on SR 39

- Test Performed between 10/05/2009 and 10/09/2009
- Four Locations
  - Total Number of Rockfalls:
- Crews
  - Survey Crew from District 7 & HQ
    - Kevin Akin
  - Maintenance Crew from District 7
  - CT Video Team from District 7
    - Steve Devorkin
  - Geotechnical Services
    - John Duffy, Bill Webster, Hung Po Yang, Seungwoon Han, David Jang, Michael Salisbury

General Rockfall Concepts

- Hazards from rocks falling from slopes adjacent to roadways
- Caused by gravity, assisted by other mechanisms
- On slopes 33° or steeper
- Evaluation is based on:
  - Maximum Energy Level (M.E.L.)
  - Climate (“Water”)
  - History (“local maintenance”)
  - Risk (decision site distance, speed limit, roadway width, etc.)

Test Sites


Satellite
Traffic
Angeles National Forest
Falling Springs
Mt Wilson
Mt Baldy
Big Pines
Wrightwood
Lytle Creek
Cajon Junction
Lone Pine Canyon Rd
Montrose
La Cañada Flintridge
Verdugo City
Montecito Park
Burbank
Altadena
Kinneloa Mesa
Sierra Madre
Chevy Chase
College Hills
Pasadena
Northeast
Lynwood
Monrovia
Duarte
Azusa
Glendora
Bonita
San Antonio Heights
Coyote Canyon
Sheridan Estates
Hillside Rd
Banyan St
Etiwanda
Glendale
Griffith Observatory
Eagle Rock
South Pasadena
East Pasadena
Arcadia
San Marino
Mayflower Village
Temple City
Irwindale
Citrus
San Dimas
La Verne
Alta Loma
Foothill Blvd
Arrow Blvd
Rancho Cucamonga
6th St
Upland
Claremont
Cable Airport
Brackett Field
Alhambra
San Gabriel
North El Monte
Vincent
Charter Oak
Rosemead
El Monte Airport
Baldwin Park
West Covina
Covina
Montclair
Ontario
Monterey Park
El Monte
West Puente Valley
Walnut Valley
Pomona
Ontario International Airport
Los Angeles
South San Gabriel
South El Monte
Avocado Heights
Valinda
Diamond Bar
Phillips Ranch
Declezville
Southridge Village
East Los Angeles
Pomona Fwy
Montebello
La Puente
South San Jose Hills
Walnut
Chino
Glen Avon
Van Buren Boulevard
Vernon
Huntington Park
Commerce
Maywood
Pico Rivera
Whittier
Hacienda Heights
Chino Hills
Los Serranos
Edison Ave
Mira Loma
Pedley
Florence-Graham
Bell
Bell Gardens
Cudahy
West Whittier-Los Nietos
Rowland Heights
Valle Lindo
Chino Airport
Eastvale
South Gate
Downey
Santa Fe Springs
South Whittier
La Habra Heights
Arroyo Pescadero Park
Sleepy Hollow
Firestone Boy Scout Reservation
Watts
West Athens
Lynwood
East La Mirada
La Habra
Orange Fwy
Butterfield
Map data ©2012 City of Pasadena, Cybercity, Google -
Edit in Google Map Maker
Report a problem

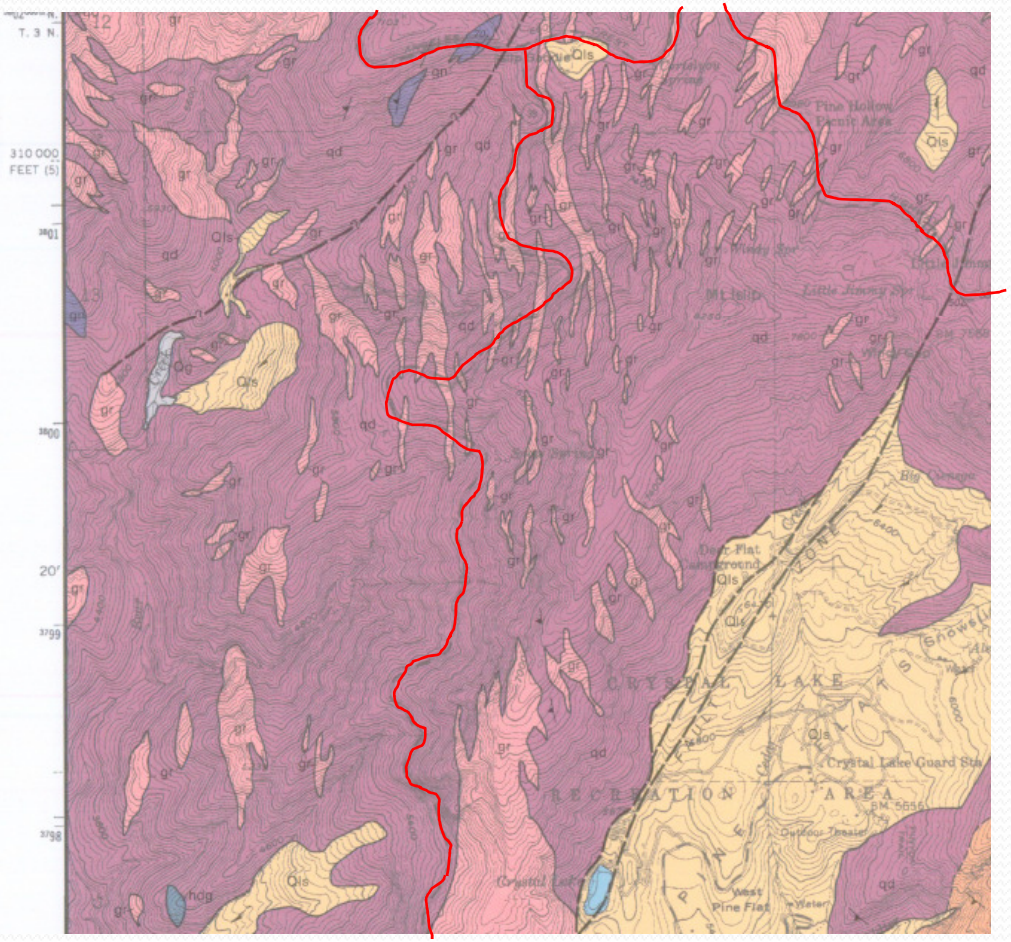
SR-39

- Narrow two-lane roadway
- located in steep mountainous terrain
- Traverses the west-facing slope of Mt. Islip
- Natural slopes vary from 20° to 40 ° from horizontal
- Elevations vary from 5600 ft amsl at the south end of the project to 5900 ft at the north end of the project

San Gabriel Mountain Range

- Characterized by deep, v-shaped valleys
- Steep ridges and peaks
- Uplifting at a rate of 3 millimeters per year
- Natural soil cover is very thin along ridges and peaks
- Valleys have thicker soil cover, dominated by boulders & coarse sedimentation from erosion of canyon slopes; may have stream channels
- Sparsely forested; intense precipitation (~ 30 in/yr in the project area)
- Severe freeze-thaw conditions with heavy natural erosion

Geology



Fine-grained Granodiorite:

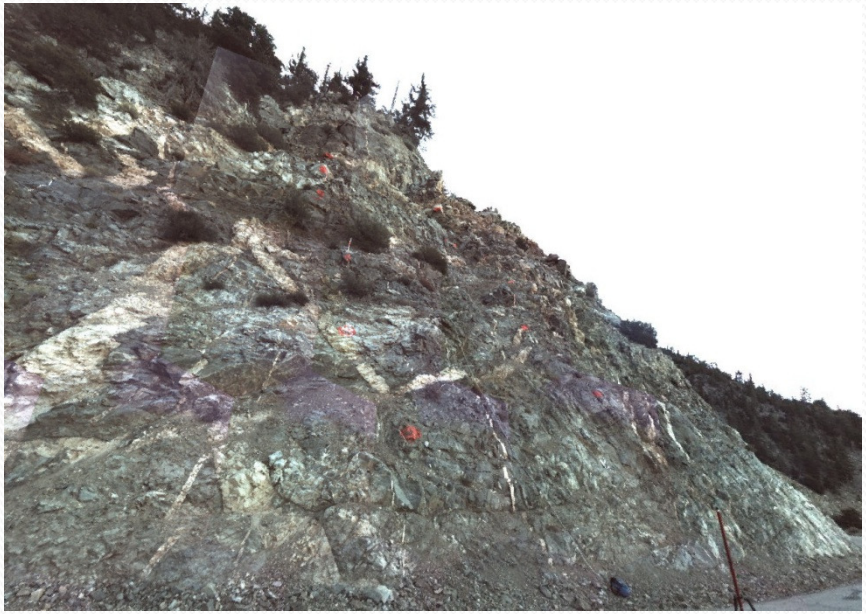
- Moderately hard
- Intensely fractured
- Moderately weathered

Gray Quartz Diorite:

- Hard
- Slightly fractured
- Slightly weathered

Covered by thin, discontinuous colluvium

Location 1 (Angle A)



Quartz veins in Gray Quartz Diorite:

- Hard
- Moderately fractured
- Weathered

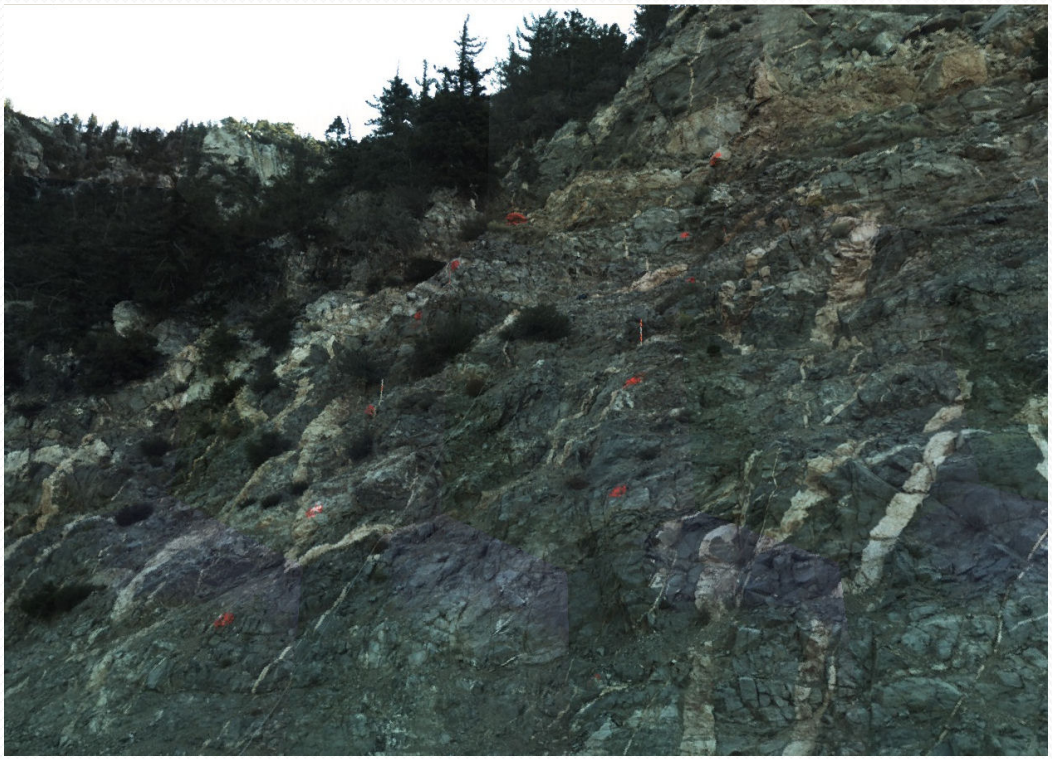
Maintenance characterized location as:

- Many rockfalls
- Some were too large to move by truck (~ 6 feet largest diameter)

Slope length ~174 feet

Slope angle ~53°

Location 1 (Angle B)



RHRS score = 408

Proposed Mitigation:

- Cable Drapery
- Standard Barrier
- Hybrid Barrier

More than one proposed mitigation involves a barrier. The geometry of the slope and roadway provide a high score. The risk to motorist in each rockfall event is likely to be very severe.

Location 2 (Angle A)

Fine-grained Granodiorite:

- moderately fractured to intensely fractured
- hard
- weathered

Maintenance characterized this location as:

- Avalanches in chutes
- Many rockfalls

Slope Length = 140 feet

Slope Angle ~ 55°

Location 2 (Angle B)

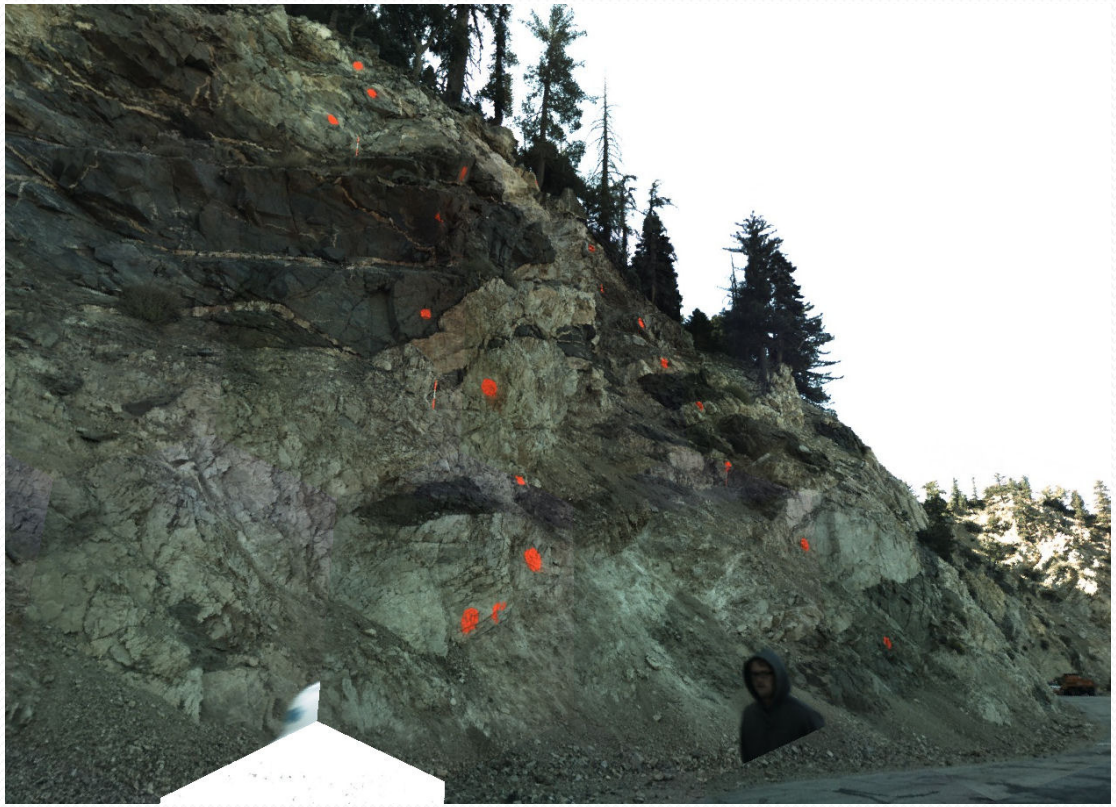
RHRS Score = 308

Proposed mitigations:

- Hybrid
- Barrier
- Drapery
- Anchored Mesh

Considered a priority because a standard barrier would potentially mitigate rockfall hazard

Location 3 (Angle A)



Gray quartz diorite and fine-grained Granodiorite:

- Hard to moderately hard
- Intensely fractured
- Weathered

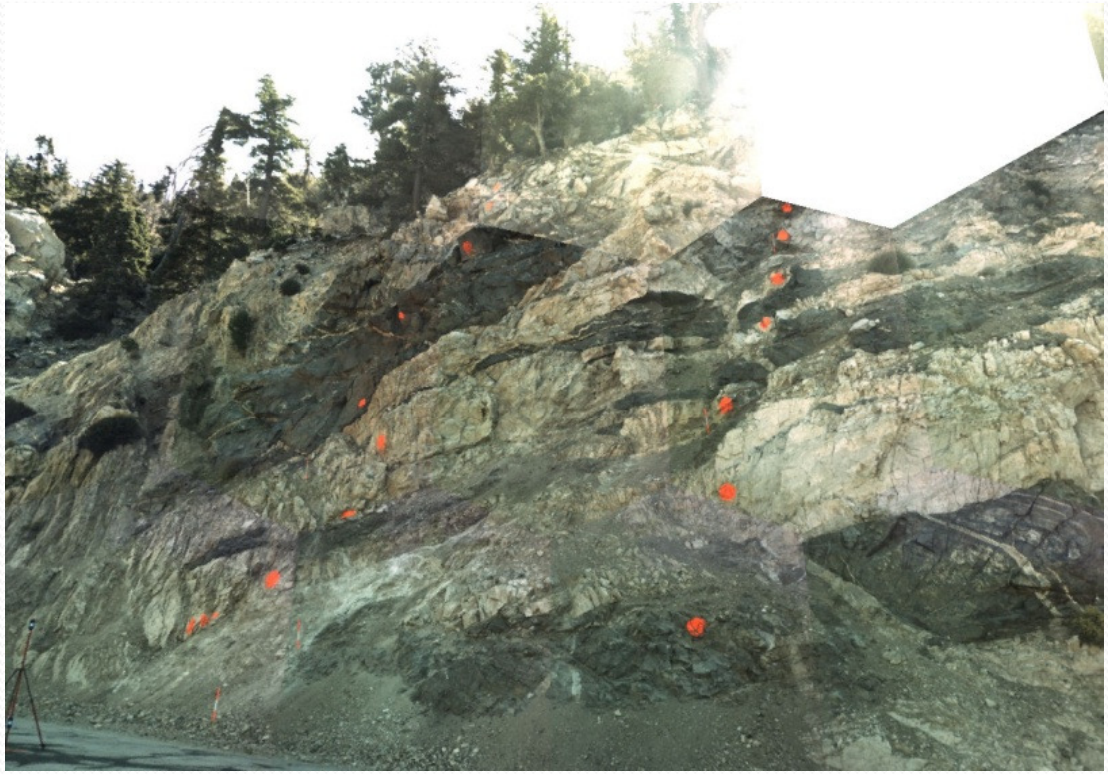
Maintenance characterized this location as:

- Rockfalls
- Rockslides
- Avalanches in chutes
- Many falls

Slope length ~141 feet

Slope angle ~ 52°

Location 3 (Angle B)



RHRS score = 421

Proposed Mitigation:

- Hybrid
- Drapery
- Anchored Mesh
- Barrier

Considered a priority because of rockfall history and barrier is a proposed mitigation. Geology and Structure of the slope is different from previous Location 1 & 2.

Location 4 (Angle A)

Fine-grained Granodiorite:

- Hard to very hard
- Moderately fractured
- Slightly weathered

Maintenance characterized this location as:

- Active rockfall
- Clean ditch frequently

Slope length ~ 143 feet

Slope angle ~ 45°

Location 4 (Angle B)

RHRS score = 437

Proposed Mitigation:

- Cable Drapery
- Anchored Mesh
- Barrier

This location is a priority due to the high score and maintenance history of persistent rockfall. This slope has similar geology to Location 2 however it has more soil cover.

Rockfall Tests

- Tasks for Each Location/Rockfall
  - Mark Reference Points
  - Survey and LIDAR
  - Roll Rock
  - Record Video
  - Measure (Weight of Rocks and Distance from Edge of Slope)
    - Load cell and rock net
  - Clean-up

4000 ft

3000 ft

2000 ft

1000 ft

Collected Information

- Survey Data
  - ASCII format data
    - Slope geometry
    - Reference points
    - Camera locations
  - Needs to be visualized
- Video records
  - VOB format
    - Cannot be played in normal CT computers
  - Need to be edited and converted into AVI format

Outcome

SITE4.asc - Notepad

File Edit Format View Help

```
6606154.556604 1949500.101768 6642.296841 44 236 242 238
6606132.145230 1949648.576603 6527.821309 126 99 101 83
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6606181.425333 1949711.716605 6534.431035 115 73 75 59
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Home Insert Page Layout Formulas Data Review

Normal Page Layout Page Break Preview Custom Views Full Screen

Ruler Formula Bar Gridlines Headings Message Bar

Workbook Views Show/Hide

B2 =DV5_L2R02_xyzpts!B2+NEelev_off

	A	B	C	D	E
1	Frame	Northing	Easting	Elevation	
47	46	1947113.614	6605849.178	6351.485545	
48	47	1947113.489	6605848.811	6350.224702	
49	48	1947113.506	6605848.265	6348.88058	
50	49	1947113.552	6605847.311	6347.361067	
51	50	1947112.815	6605846.582	6345.889015	
52	51	1947112.507	6605846.268	6344.612238	
53	52	1947112.328	6605845.66	6342.891798	
54	53	1947112.041	6605845.111	6341.363755	
55	54	1947111.695	6605844.367	6339.996927	
56	55	1947111.383	6605843.89	6338.031457	
57	56	1947111.194	6605843.231	6336.659531	
58	57	1947111.136	6605842.58	6334.950012	
59	58	1947110.657	6605842.12	6332.606002	
60	59	1947110.483	6605841.66	6331.181415	
61	60	1947110.349	6605840.875	6329.357613	
62	61	1947110.054	6605840.708	6327.526637	
63	62	1947109.7	6605839.497	6326.315757	
64	63	1947109.366	6605838.675	6325.661064	
65	64	1947109.669	6605836.685	6325.131693	
66	65	1947110.11	6605835.524	6325.096778	
67	66	1947110.276	6605834.619	6324.820101	
68	67	1947110.086	6605833.097	6324.278468	
69	68	1947110.598	6605831.767	6324.054635	
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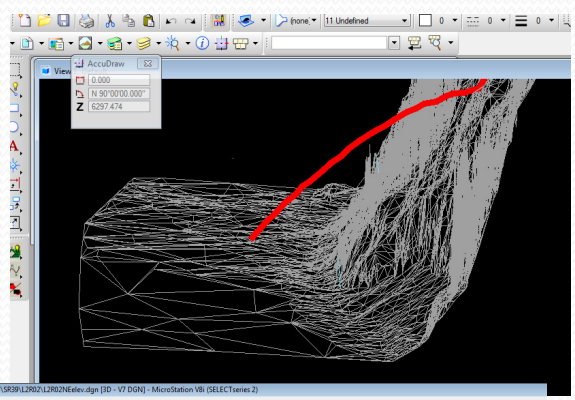
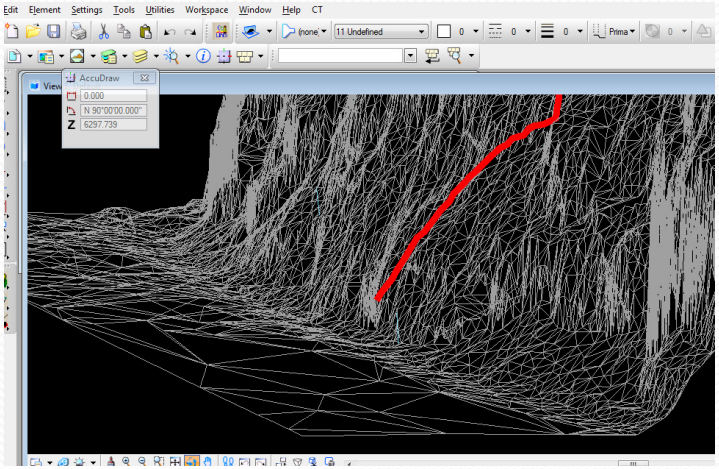
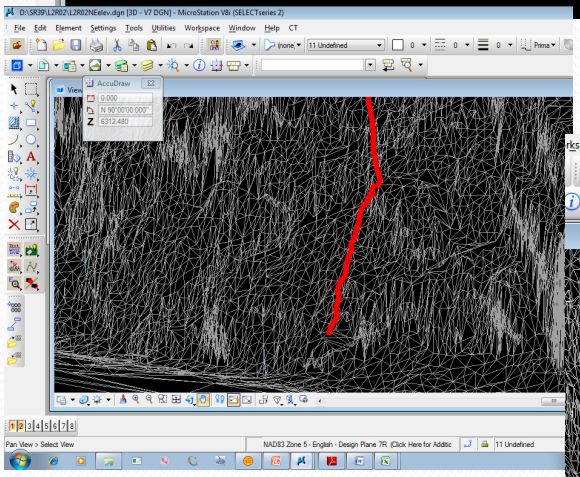
DV5_L2R02_xyzpts NEelev_offset Rock_N_E_Elev Import

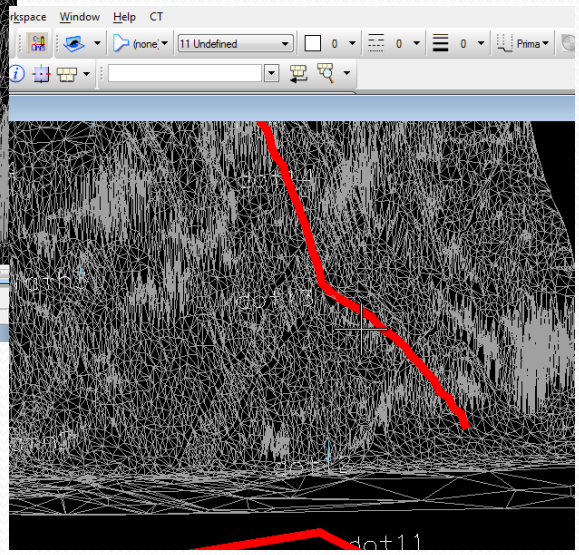
Ready

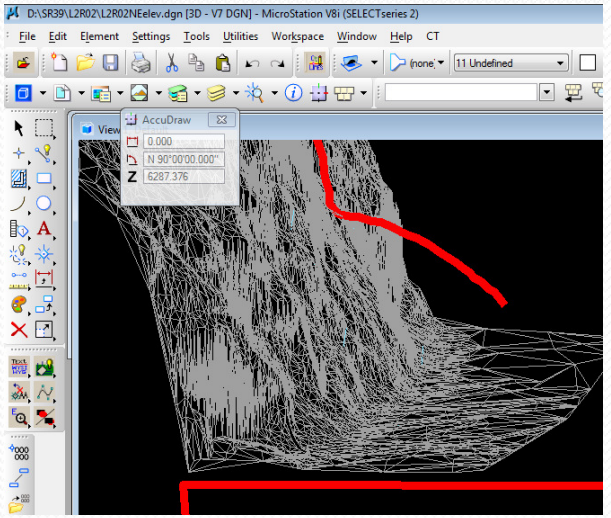
3-D CAD from Analysis











Trajectory

- A cross section of rock trajectory from x,y,z positions can provide:
  - Bounce height (i.e. will barriers work)
  - Energy toward impact
  - Calibrate software
  - Determine parameters for simulation
  - Evaluate how aggressive our simulations may be.

Trajectory and Energy

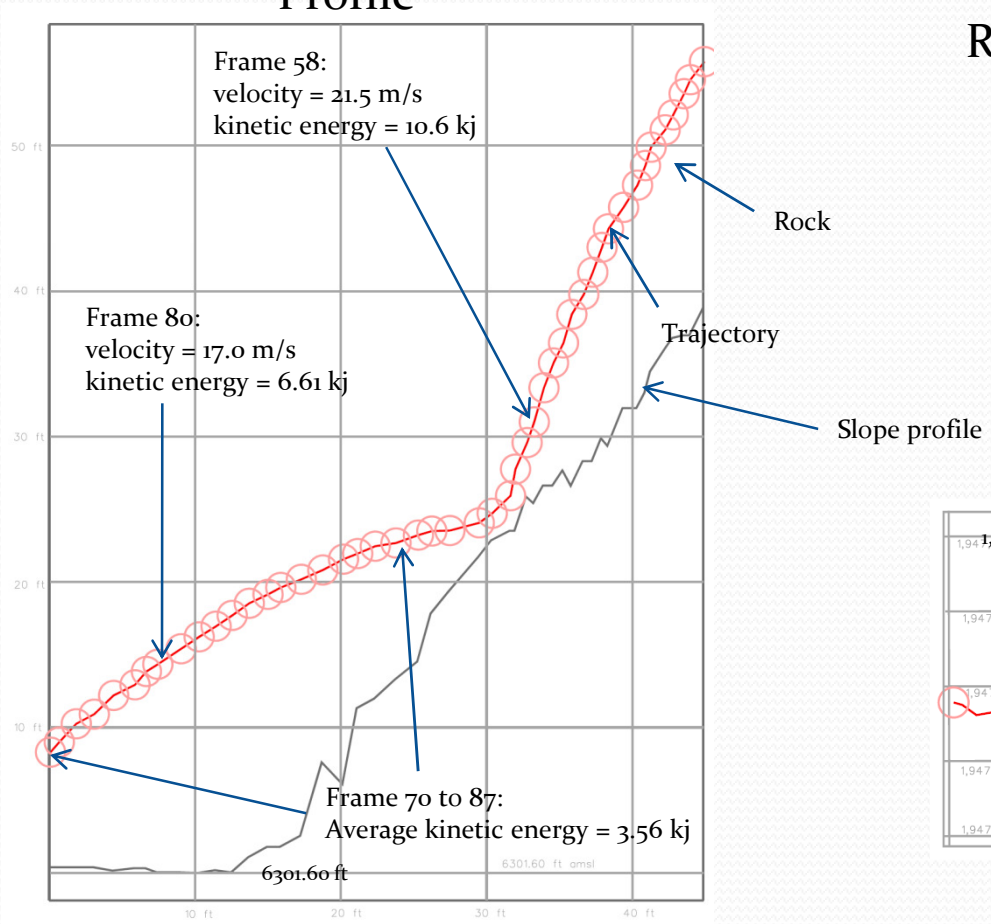
- Trajectory is determined from frame to frame by:
  - Distance:

$$x = \sqrt{\Delta Northing^2 + \Delta Easting^2 + \Delta elevation^2}$$

  - The elevation is plotted against distance to make a profile
- Energy is determined by:
  - Time = 30/1001 seconds
  - Speed = Distance/time
  - Energy = ½ mass x speed^2

Trajectory Profile and Energy Location 2 Rock 2

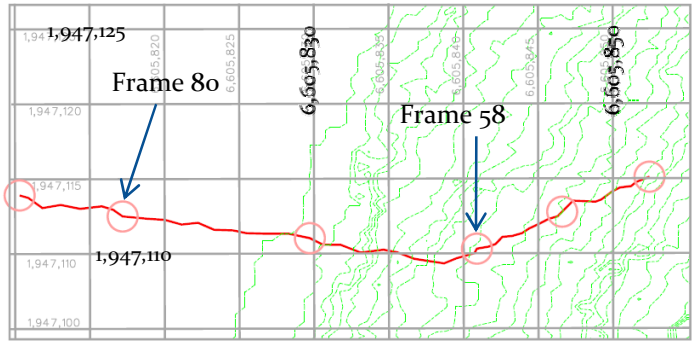
Profile



Rock Parameters:

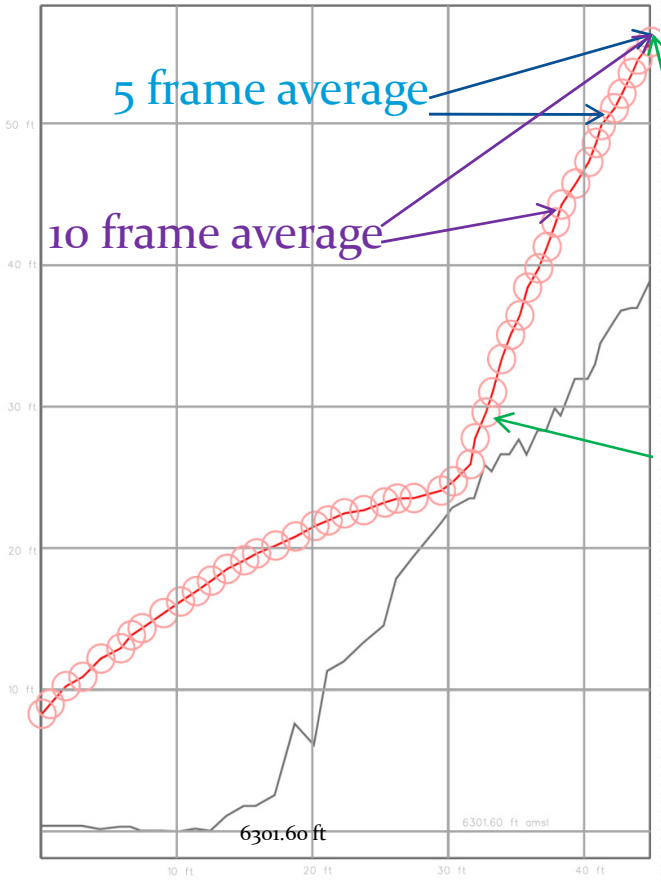
- Weight = 101 lbs
  - mass = 3.14 slugs (45.8 kg)
- Initial length = 26 inches
- Initial depth = 17 inches
- Initial width = 7 inches

Plan View



Energy Analysis

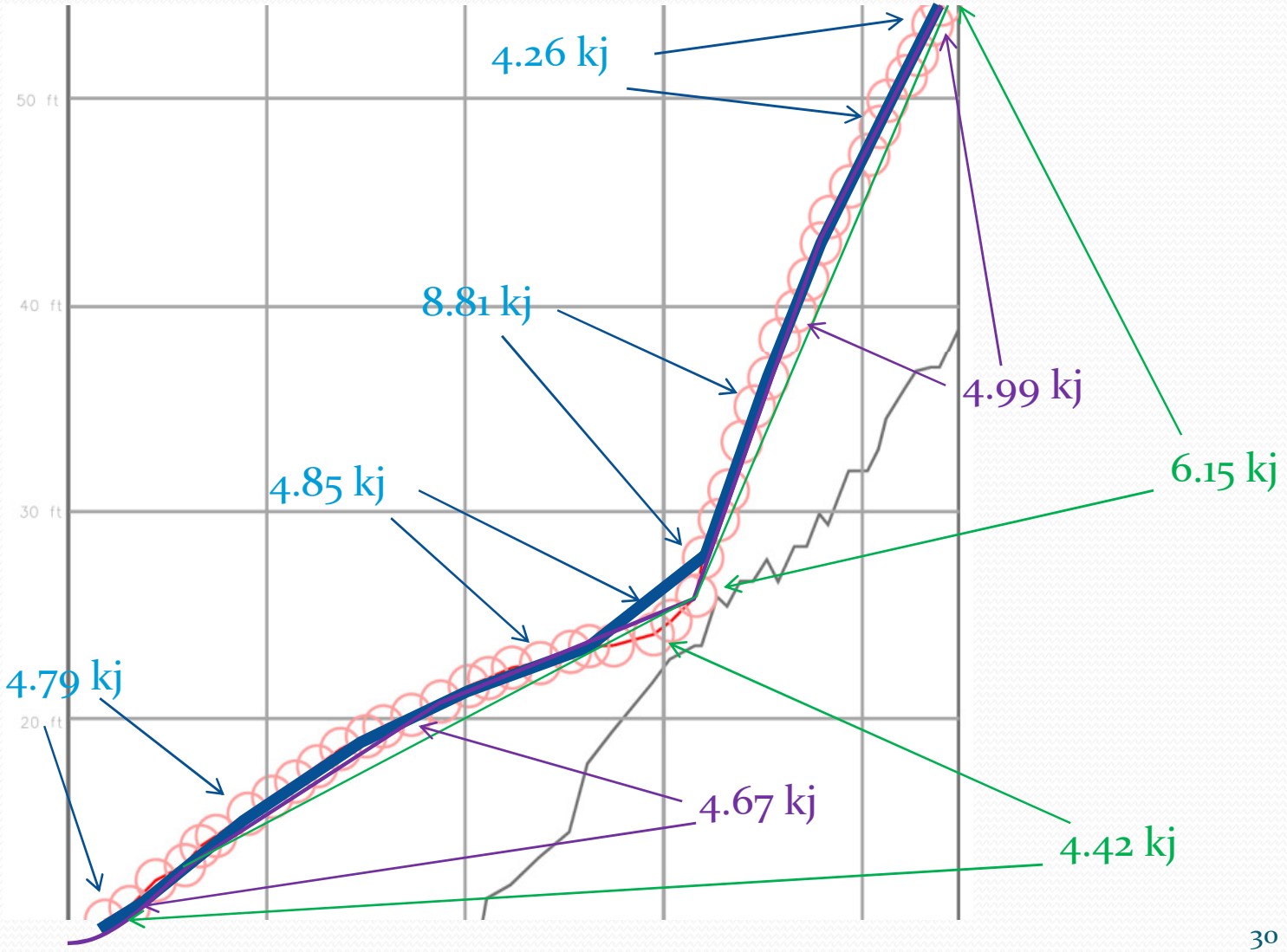
Profile



$$\frac{\sum x_{frame/frame}}{\sum \Delta frame * \frac{30}{1001}} = kinetic\ energy\ from\ frame\ A\ to\ frame\ B$$

$$\frac{\sqrt{\Delta N_{A\ to\ B}{}^2 + \Delta E_{A\ to\ B}{}^2 + \Delta elev_{AtoB}{}^2}}{\sum \Delta frame * \frac{30}{1001}} = \bar{k}$$

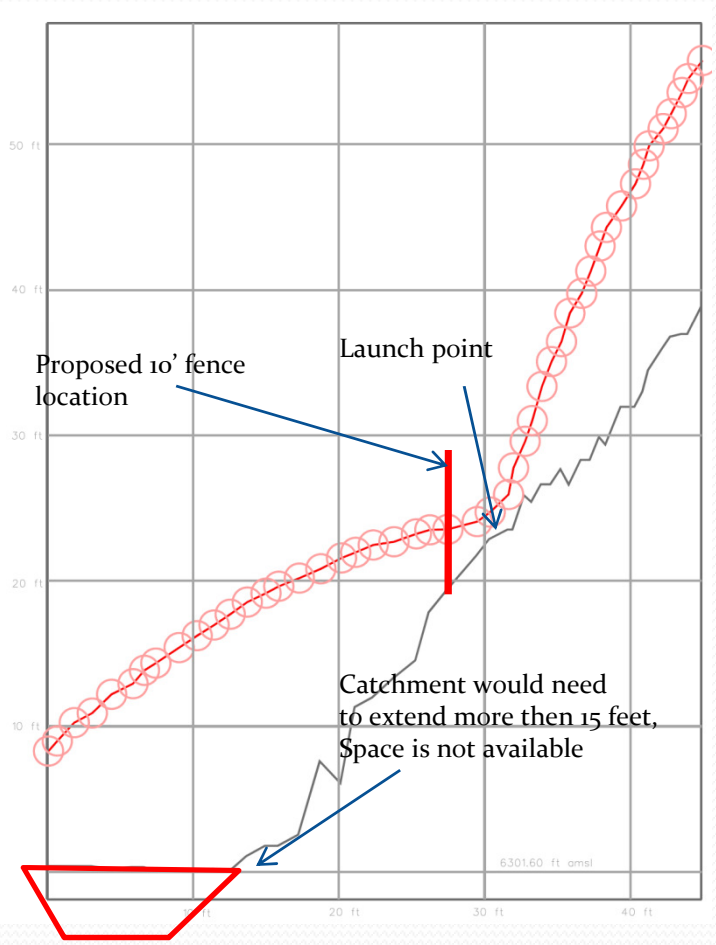
Frame to Frame Energy



Field Data compared to Video Rock L2R02

Results Based on Field Measurement			*Results Based on Video*			
PE (kj)	Ave. K (kj)	PE (kj)	Ave. K (kj)			
			total trajectory	last 5 frames	last 10 frames	last 20 frames
14.6	1.2	6.49	5.46	4.79	4.67	4.42

Results



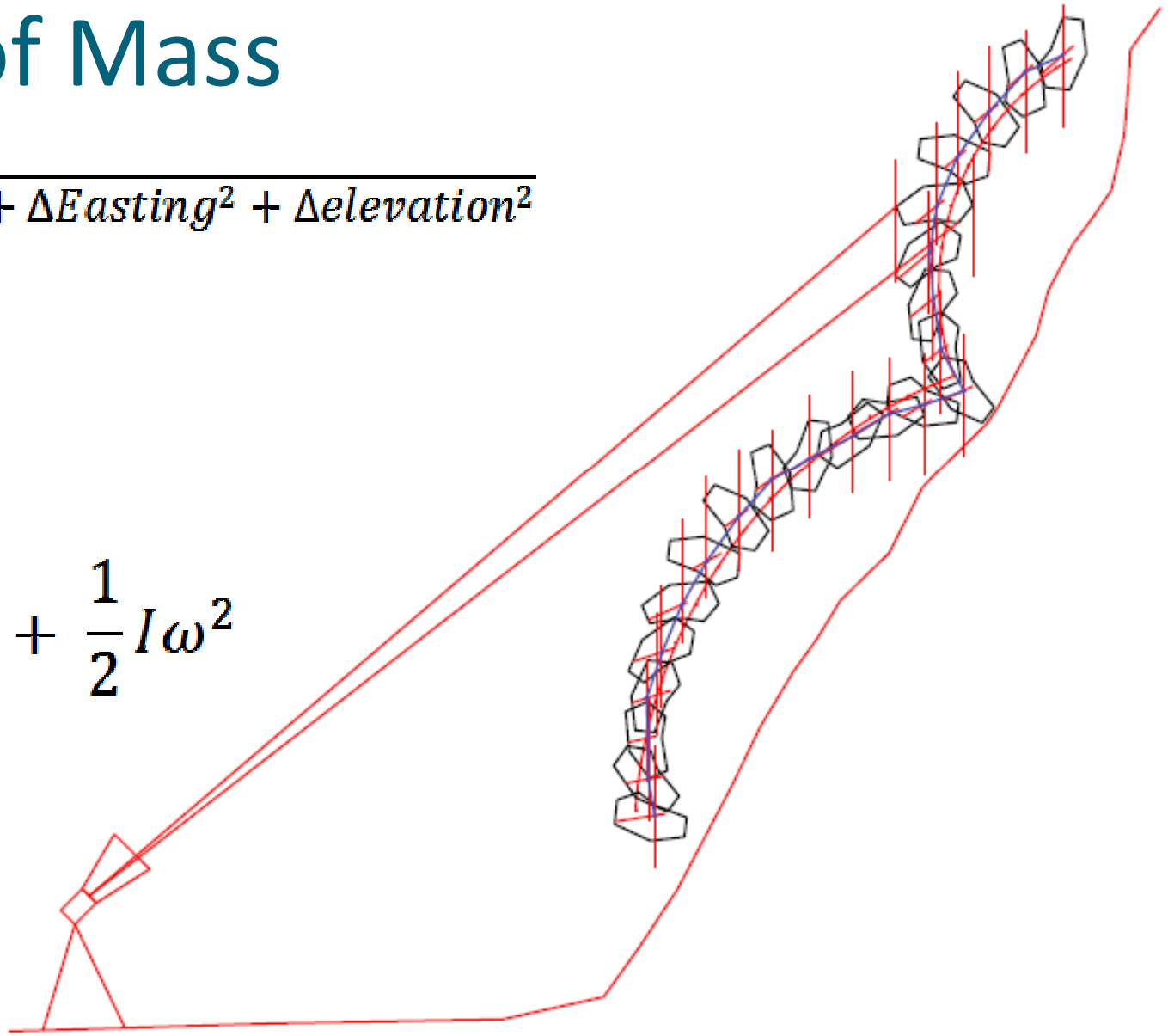
- For location 2 a proposed fence might be placed at the redline
- If other rocks miss this point, a barrier may not be useful here
- Redeveloping a catchment may not be feasible
- Drapery could be a better alternative

Center of Mass

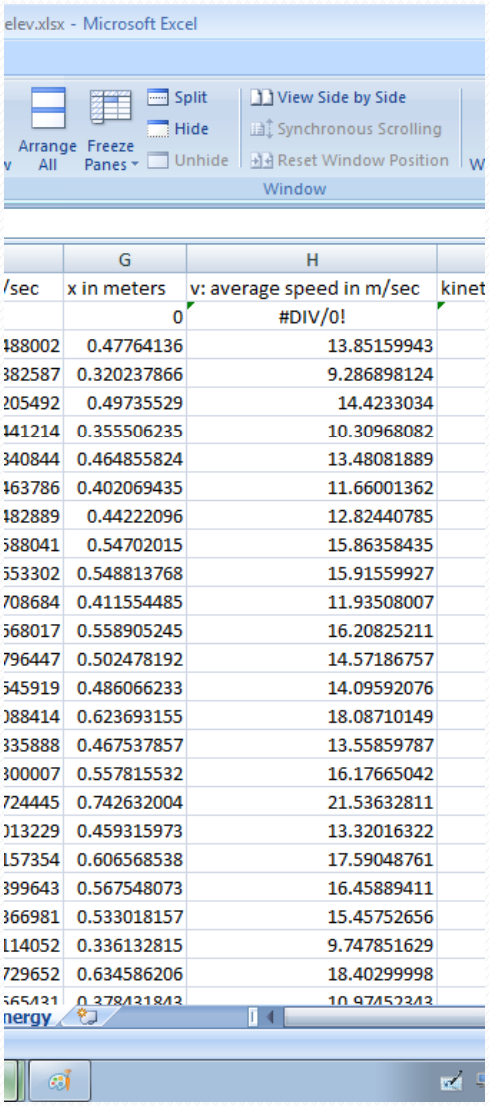
$$x = \sqrt{\Delta Northing^2 + \Delta Easting^2 + \Delta elevation^2}$$

$$\frac{x}{t} = v$$

$$k = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$



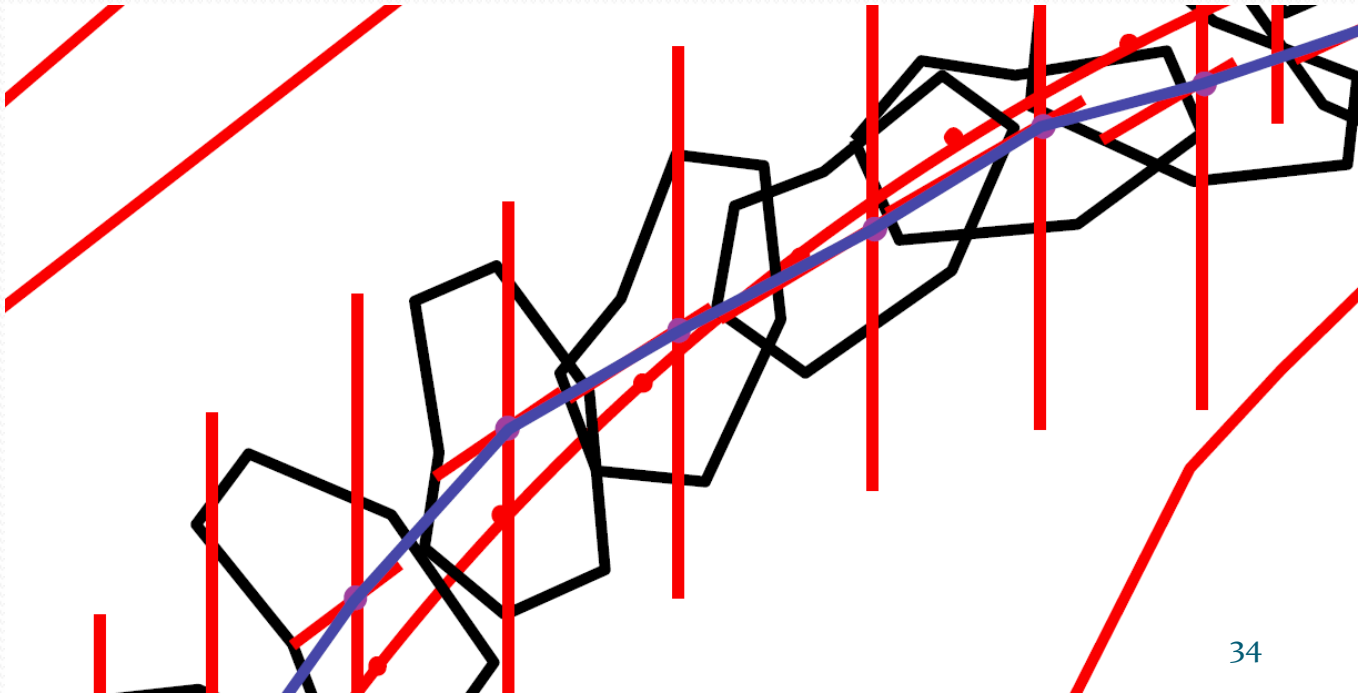
Center of Mass



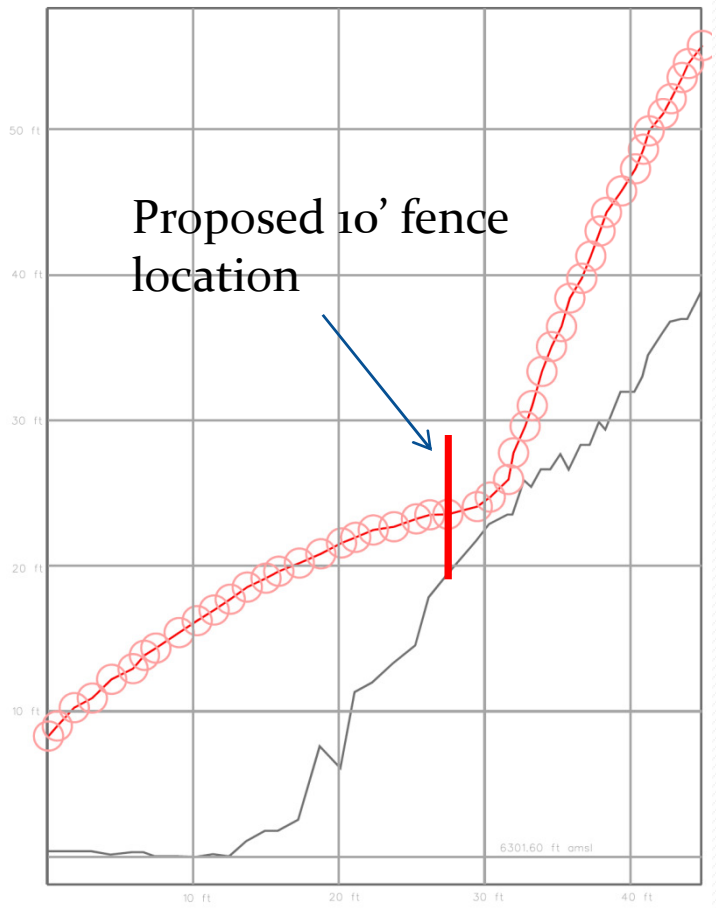
	G	H	
/sec	x in meters	v: average speed in m/sec	kinet
	0	#DIV/0!	
488002	0.47764136	13.85159943	
382587	0.320237866	9.286898124	
205492	0.49735529	14.4233034	
441214	0.355506235	10.30968082	
340844	0.464855824	13.48081889	
463786	0.402069435	11.66001362	
482889	0.44222096	12.82440785	
588041	0.54702015	15.86358435	
553302	0.548813768	15.91559927	
708684	0.411554485	11.93508007	
568017	0.558905245	16.20825211	
796447	0.502478192	14.57186757	
545919	0.486066233	14.09592076	
088414	0.623693155	18.08710149	
335888	0.467537857	13.55859787	
300007	0.557815532	16.17665042	
724445	0.742632004	21.53632811	
013229	0.459315973	13.32016322	
157354	0.606568538	17.59048761	
399643	0.567548073	16.45889411	
366981	0.533018157	15.45752656	
114052	0.336132815	9.747851629	
729652	0.634586206	18.40299998	
565431	0.378431843	10.97452343	

$$\frac{0.4572^{m}}{0.02997^{sec}} = 15.26^{m/sec} \rightarrow \frac{1}{2}45.77 \times 15.26^{2} = 5.392^{kj}$$

$$\frac{0.1524^{m}}{0.02997^{sec}} = 5.09^{m/sec} \rightarrow \frac{1}{2}45.77 \times 5.09^{2} = 0.592^{kj}$$



Conclusions



- Trajectory Profile w/o Energy:
  - We can visualize effectiveness of barriers
  - Determine barrier height
- Trajectory Profile w/ Energy:
  - Provides a conservative estimation of energy